ATMOSPHERIC PROCESSES IN THE 30-60 km LAYER DURING 1971-1973

I. V. Bugayeva and L. A. Ryazanova

Tsentral'naya Aerologicheskaya Observatoriya,
Leningrad, USSR

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16. Abstract

Systematic, weekly, upper-air contour charts constructed from data obtained at rocket sounding stations in the Northern hemisphere are discussed. These charts, which cover the period from August 1971 to December 1973 and describe the 35, 40, 45, 50, 55 and 60 km levels, are used to obtain information about processes in the upper stratosphere and lower mesosphere during the spring and autumn reversals and the winter anomalous warmings. It is shown that the dates of the spring reversal of the meteorological fields in the stratosphere depend on the phase of the quasi-biennial cycle and on the nature of the processes in the winter warmings.

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I. V. Bugayeva and L. A. Ryazanova

Tsentral'naya Aerologicheskaya Observatoriya,
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Upper-air contour charts have been constructed by the Phys- /46*
ics of the Upper Layers of the Atmosphere section, Central Aerological Observatory since August 1971, for 6 levels: 35, 40, 45, 50, 55, and 60 km. These charts are constructed from sounding data of 15 rocket stations located in the northern hemisphere, transmitting information in ROKOB code. In connection with the small number of the stations used, at which sounding is carried out once a week, on the average, the charts are not constructed daily, but weekly. These charts cannot pretend to be absolutely accurate but, nevertheless, they are very important material, which can be used in analysis of the processes in the upper stratosphere and mesosphere on a global scale. They also can be used for evaluation of the representative nature of the data of different rocket stations. In the present work, the basic features of the processes in the 30-60 km layer are examined, using the weekly upper-level contour charts and the daily 10-mb surface charts, for the period from August 1971 to December 1973. Not dwelling on the chronological order of the sequence of the processes, we examine only the most interesting of them: the processes of the fall and spring reversals and the winter warmings, which were observed in the period studied.

Fall Reversals of the Meteorological Field in 1971 and 1972

The fall reversals of the meteorological field in the stratosphere and mesosphere come about with small barometric gradients,

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*Numbers in the margin indicate pagination in the foreign text.

and they are similar in general outline from year to year. However, upon analysis of the upper-air contour charts, several peculiarities were found.

In 1971, the meteorological reversal of the field from the easterly summer circulation to the westerly winter one began, with separation of a high pressure center into two centers on 21 August. This separation occurred simultaneously over the entire layer, from 30 to 60 km.

The formation of a stable low pressure region in the middle stratosphere was observed on 25 August, in the area of the mouth of the Ob, which is seen well on the 10 mb charts. From there, this region moved to the west along the latitude circle, to the coast /47 of Greenland, where it fused with other low pressure regions, which had formed in northern Canada. This combined and strengthened low pressure zone is seen well over the entire height layer, both at 35 and at 60 km. It became established in the area of the pole on 5 September. A high pressure center, displaced toward Eurasia and the Pacific Ocean, retreated to the middle latitudes, and it then fused with the subtropical maximum region.

In 1972, separation of the high pressure center on the 10 mb surface was observed on 13 August. However, formation of a stable low pressure region took place later, 30-31 August. It was over approximately the same area, over the Taymyr. The trajectory of this region to the shores of the Atlantic Ocean was similar to the 1971 trajectory, but the process itself of vertical development of the reversal took place somewhat differently: a well expressed trough in the north Atlantic, directed toward the pole, was seen at an altitude of 35 km on the 26 August-1 September chart. In the same period of time, a stable circumpolar high is still observed in the lower mesosphere, at the 55 and 60 km levels, and the trough is absent. A week later, on the 2-8 September charts,

the trough is traced into the mesosphere. Final establishment of the low pressure region above the pole took place on 12 September, i.e., a week later than in 1971. The trajectory of the high center leaving the pole also was different: initially, it was displaced to Scandinavia, passed over the Atlantic and South America at middle latitudes, and it then reached the Pacific Ocean area.

Comparing the pressures in the centers of the highs in the 30-60 km layer in August 1971 and in August 1972, it can be noted that the high in 1972 was stronger. The later fall reversal of this year possibly was connected with this. Moreover, the difference in geopotential altitudes between the high and low centers in 1972 was half that in 1971. At the 10 mb level, it amounted overall to 10 dm.

Thus, our upper-level charts permit a more or less thorough analysis of the fall reversals to be carried out.

Winter Warming in the 30-60 km Layer

In 1972 and 1973, stratospheric and strato-mesospheric warmings were observed in January and February. The nature of the warming processes in 1972 and 1973 were different. Let us examine them in greater detail.

In the first days of January 1972, the barometric field of the stratosphere, up to an altitude of 45 km, and of the mesosphere above 50 km differed sharply in structure and location of the primary pressure centers. A circumpolar low was noted in the stratosphere above the pole, extending to the continents, and two highs, located above the northern portions of the Pacific and Atlantic oceans. The centers of these high pressure areas were located in the 60-70°N latitude zone and, with height, their vertical axes inclined towards the pole. Above 55 km, in the mesosphere, they fused above the pole and formed a single high pressure system. At these

altitudes, the low pressure center was divided into separate regions, which were displaced to the continents. The warm region connected with the Pacific Ocean high advanced to the near-polar areas from the Eurasian continent. However, the temperature increase was observed only at the mesosphere levels. The temperatures in the mesosphere were 20°C above normal. The heat did not penetrate to the stratosphere.

Thus, this warming was mesospheric, since neither barometric /48
reversal, increase in temperature nor east winds were observed in the stratosphere. This was a short-term process, and it ended the middle of January. Over the entire layer, from 30-60 km, low pressure circulation was again established in the high and middle latitudes above the continents. Ridges or high pressure areas, which were quite stationary until the middle of February, were traced above the oceans in the stratosphere, up to an altitude of 45 km. The barometric field was a low pressure center above 45 km, occupying the entire hemisphere, right down to the equatorial zone. A second warming began in the second half of February. However, it was of a completely different nature and it was stratospheric. It was not observed in the mesosphere. In contrast to the first warming, it occurred without a significant reversal of the barometric field, although the Atlantic and Pacific Ocean highs approached the pole closely. These highs were not traced above 45 km. The warming was somewhat more extensive in area covered than the first one, but it was of low intensity, and it ended at the end of February.

In this manner, two relatively brief warmings were observed in the winter of 1972, which were different in structure: one was mesospheric and the other, stratospheric. The first took place with a barometric reversal in the upper layers and the second, without significant reversal.

Warming also was observed in the winter of 1973, in January and February. Apparently, two waves of a single process were noted.

The first warming wave was observed in the mesosphere, and it was not accompanied by a radical reversal of the meteorological field. It was caused by activation of the Pacific Ocean high, which advanced to the pole in the first days of January 1973. Its upper boundary was above 55 km. A ridge also extended to high latitudes from the Atlantic Ocean. Splitting of the low pressure center and a rise in pressure in its centers, displaced to the continents, was observed in the upper and middle stratosphere. The temperature in the polar regions increased by approximately 30°C above normal during warming (45 km above Hayes Island), and it held on for several days. However, the warm region did not extend below 40-45 km. Strong meridional winds were noted at many stations in this period.

The warming process weakened in the middle of January. The low pressure areas became a single one, and the pressure began to fall in it. However, the Pacific Ocean high did not leave the Bering Sea area.

The second warming wave began on 25 January, and it was accompanied by sharper changes in the barometric and circulation fields of the stratosphere and lower mesosphere. Reversal of the barometric field began in the mesosphere, and it was accompanied by fusion of the Pacific Ocean and Atlantic highs into a single system [2]. This reversal did not occur in the stratosphere, although a ridge of the Pacific Ocean high extended quite far into the near-polar region. However, the low pressure center was a single pressure system. Spread of the pressure field reversal from the mesosphere to the stratosphere was observed in the first week of February (Fig. 1a). Descent of the warm region and east winds in the lower stratosphere were noted simultaneously. This is seen in the temperature-wind profile for Hayes Island [2]. In turn, the

opposite process came about in the mesosphere at this time, formation of cold foci, with temperatures of -110°C at altitudes of 75-80 km [2] and restoration of the low pressure field (Fig. 1b). Thus, the charts constructed allowed it to be seen that the process of reversal of the pressure field at the time of the warming first /50 began at the higher, mesospheric levels, and that restoration of winter circulation also began at the higher levels.

Breakdown of the high pressure structure of the field in the stratosphere was noted after 10 February. The polar regions were again occupied by a low pressure center, but a sedentary high pressure area, the height of which was not over 45 km, held on above the Pacific Ocean until the end of February. In connection with this, the low pressure center was displaced from the pole towards Greenland. Compared with 1972, this warming was more intensive, and it was recorded by many polar stations. We also note that the speed of the meridional wind was over 100 m/sec during this time.

Thus, the winter 1971/1972 and 1972/1973 warmings were completely different, in both intensity and nature of the processes and structure of the pressure and circulation field: in the winter of 1971/1972, the warming was quite weak and of a local nature; the warming was quite weak and was of a local nature: the first was only mesospheric and the second, only stratospheric. In the winter of 1972/1973, the warming was somewhat stronger, and it appeared in the entire layer, from 30-60 km, i.e., it was stratomesospheric. It began above and it spread downwards, with complete reversal of the pressure field. The upper-air contour charts made it possible to trace the spread of this process from the mesosphere to the stratosphere. Similar warmings, with complete reversal of the pressure field, took place in 1958, 1963, 1968 and 1971. After this kind of late warming, the spring reversal occurred at the end of April, beginning of May, i.e., it also was later.

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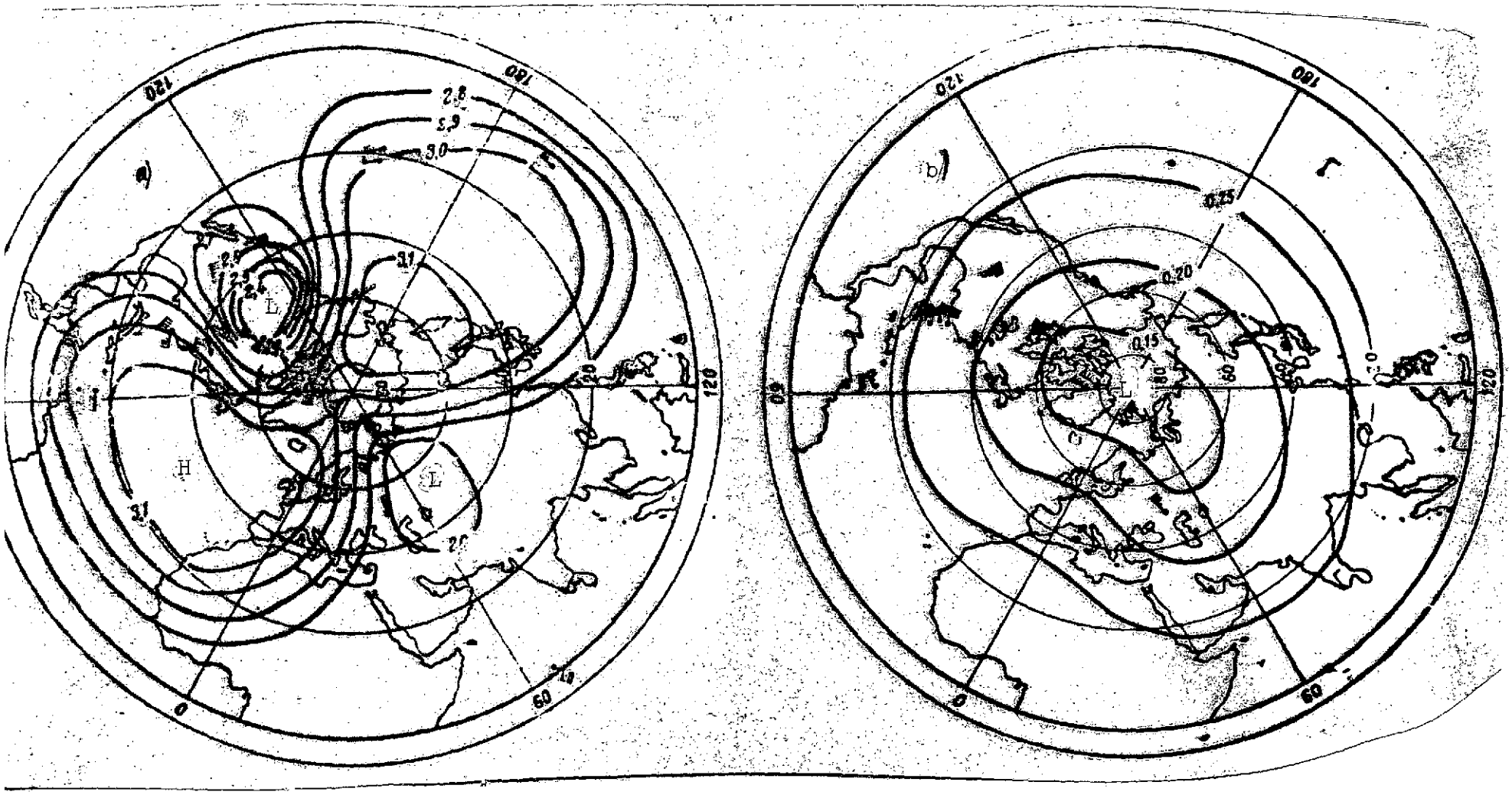

Fig. 1. Spread of pressure reversal from the mesosphere to the stratosphere (3-9 February 1973) at altitude of 40 km (a) and restoration of the low at altitude of 60 km (b).

To confirm this hypothesis, we examined the stratospheric processes (10 mb) in the winter and spring, from 1958 to 1973, and we compared them with the phases of the quasi-biennial cycle, taken from works [1, 3].

In study of these processes, the principal attention was given to the intensity of the stratospheric warmings and the times they ended, as well as to the dates of reversal of circulation to the summer regime (dates before 1972 were taken from [3, 4]). The main characteristics of the processes are presented in Table 1. An analysis of the material showed that, with strong late warmings, the ending of which was noted in February, the spring circulation reversals were late. This was observed in 1958, 1962, 1963, 1966, 1969, 1970 and 1973. All the late spring reversals, except 1966, 1969, and 1973, corresponded to a specific phase of the quasi-biennial cycle wind, replacement of the easterly phase by the westerly, which then reached a maximum, or retention of the easterly phase was noted.

Nearly all the spring reversals at the average time (middle of April) also were observed during the easterly phase of the quasi-biennial cycle. However, in this case, stratospheric warming always ends in January. 1960 and 1972 are exceptions. Very weak final warmings, ending at the beginning of March and which did not affect the time of the spring reversal, were noted then (Table 1).

Early spring reversals took place 4 times in the period of time being considered: in 1959, 1961, 1964 and 1971. We note that, in 1959 and 1961, the stratospheric warmings were weak and ended at the end of January. In 1971, a strong stratospheric warming was noted, but it ended the middle of January. Analysis of the quasi-biennial cycle phase has showed that replacement of the easterly cycle by the westerly was observed in these years, and the latter then reached its maximum growth. The warming in 1964 also was

characterized by low intensity, and it ended in the first days of February. Apparently, this, in combination with the replacement /51 of the easterly phase by the westerly, which was of short duration, made the early spring reversal possible.

Table 1. Characteristics of Warmings, Spring Reversal Dates and Cycle Change in the Equatorial Region

Year	Intensity of Warming	Time of End of Warming	Times of Circulation Reversal to Summer Regime	Cycle shift in Equatorial Region	Maximum Phase of Cycle
1958	strong*	16—17 Feb	10 May	W→E	E
1959	weak	28 I—2 Feb	20 Mar	E→W	W
1960	»	2—4 Mar	17 Apr	W→E	E
1961	»	25 Jan	15 Mar	E→W	W
1962	»	25—27 Feb	1 May	W→E	E
1963	strong	7—8 Feb	10 May	E	E
1964	weak	5 Feb	19 Mar	E→W→E	E
1965	»	12 Jan	18 Apr	E	E
1966	strong	27—28 Feb	25 Apr	E→W	W
1967	weak	20—22 Jan	27 Apr	W→E	E
1968	strong	15—17 Jan	28 Apr	E	E
1969	»	20—25 Feb	16 Apr	E→W	W
1970	»	28 I—4 Feb	27 Apr	W→E	E
1971	»	20—25 Jan	22 Mar	E→W	W
1972	weak	2—4 Mar	16—18 Apr	W→E	E
1973	strong	25 Feb	11 May	E→W	W

*A strong stratospheric warming is understood to be a process, in which a temperature increase of more than 40°C above the average value is observed in the polar region, in the 30-50 km layer. In the majority of cases, this is accompanied by a pressure field reversal (establishment of a high in the area of the pole).

The processes in 1966, 1969 and 1973, when the westerly phase maximum in the equatorial region did not correspond to the times of the spring reversal of the circulation field, must be decided on separately. As is seen from Table 1, a late reversal of the circulation to the summer regime was noted in these years, while the reversal should be early with the westerly phase. The reason for disruption of the correspondence between the quasi-biennial cycle

phases and the times of the spring reversal apparently was powerful stratospheric and mesospheric warmings, which ended only at the end of February. A comparison of the dates of ending of the warmings and reversal of the circulation to the summer regime (Table 1) shows that 1-1/2 or 2 months usually elapses between them. Consequently, in 1966, 1969 and 1973, the spring reversals had to occur at the end of April, beginning of May, which actually was observed.

In this manner, the following can be concluded from the material analyzed. The times of onset of the spring reversal are determined, not only by the phase of the quasi-biennial cycle in the equatorial region, but they also depend, to a considerable extent, on the intensity of the stratospheric warmings and the times they end.

Spring Reversals of Pressure Field in 1972 and 1973

In 1972, the low pressure center in the stratosphere had already left the area of the pole by 18 March. It was displaced to Novaya Zemlya and then to the northern Urals and, by the end of March, it had moved to the east, along 60-65°N latitude. In this /52
period of time, a high pressure area at 55°N latitude above the center of the North American continent began to advance rapidly towards Alaska and then towards the Chukotskiy sea, where it stopped. It then began to shift slowly in this area. Thus, a relatively diffuse pressure field formed above the pole. But, on 27 March, the northern periphery of the high pressure area occupied the near-polar region; however, its center was finally consolidated above the pole only by 15 April, by means of fusion of 2 high pressure regions located above the mouth of the McKenzie River and above Scandinavia.

A high pressure area, which began to advance to the near-polar area in March, was low, reaching 42 km. Therefore, it accomplished a reversal only in the lower and middle stratosphere. In the upper

stratosphere and middle mesosphere, the westerly cyclonic circulation still prevailed at the end of March. At the same time, east winds appeared in the upper mesosphere, which slowly descended. In this manner, the most inert layer (in the sense of occurrence of processes) turned out to be the upper stratosphere-lower mesosphere layer.

It was not until the first week of April that the descending east winds from the upper layers fused with the stratospheric east winds and formed a single high pressure circulation in the 20-80 km layer.

Consequently, in the spring of 1972, conversion of the pressure field took place earliest of all below, in the middle stratosphere and, then, in the mesosphere and then in the remaining layer. Concerning changes in the temperature field, in a comparison of the trend of the temperatures above Volgograd and above Hayes Island at altitudes of 35, 50 and 60 km, it can be noted that the temperature above Hayes Island at 35 km was higher than above Volgograd at the same altitude on 1 April; at an altitude of 50 km on 21 March and during all of March at 60 km, it was higher than at Volgograd.

Thus, the change of the temperature gradient in the lower mesosphere occurred considerably earlier (more than a month), than in the middle stratosphere, and the pressure reversal took place later.

The processes in the spring of 1973 differ very sharply from the processes in the preceding spring. Separation of the low pressure center took place in March. However, no significant changes were observed in the processes of the layer being studied, almost until the last days of April: the pressure in the low increased gradually, it filled, but it did not leave the area of the pole.

On the charts of 14-20 April 1973, it is seen that the low pressure field prevails above the polar areas at an altitude of

35 km, and that the low pressure centers were located above the continents in the middle latitudes. High pressure areas, in the form of ridges, were directed from the oceans to the high latitudes. At an altitude of 60 km (Fig. 2a), the pressure field structure was somewhat different: the Atlantic high, which prevailed above the western hemisphere, right up to Greenland, developed the main activity. In connection with this, the low pressure system was displaced to Siberia and the Pacific Ocean. However, on subsequent charts, the low pressure at an altitude of 35 km was reduced still more and was dissected by ridges, although it stayed above the pole. There was practically no pressure reversal in the mesosphere (60 km), because of advance of a high pressure area from the direction of America. The high pressure area occupied a tremendous area, extending from the coast of Europe, through the Atlantic Ocean and North America, to the eastern portion of the Pacific Ocean. The pressure field of the stratosphere changed in the first days of May, owing to strengthening of the Pacific Ocean high. The low pressure region left Europe, and troughs went from it to Asia and Canada.

Concerning the mesosphere, the reversal processes at these levels continued to develop more in succession. On the 28 April-4 May chart, at an altitude of 60 km, it is seen (Fig. 2b) that the high had practically enveloped the entire polar region, and that /54 the low pressure region occupied a comparatively small area and was located above Europe. It is seen in the 5-11 May charts that the pressure field reversal in the mesosphere had ended. A high pressure groove was located above the pole, in the middle and upper stratosphere, but not a high pressure center. The pressure field reversal to the summer regime did not end until the middle of May.

The great differences in times and nature of occurrence of the spring pressure field reversals in 1972 and 1973 apparently are connected with a whole series of reasons. We point out some of them.

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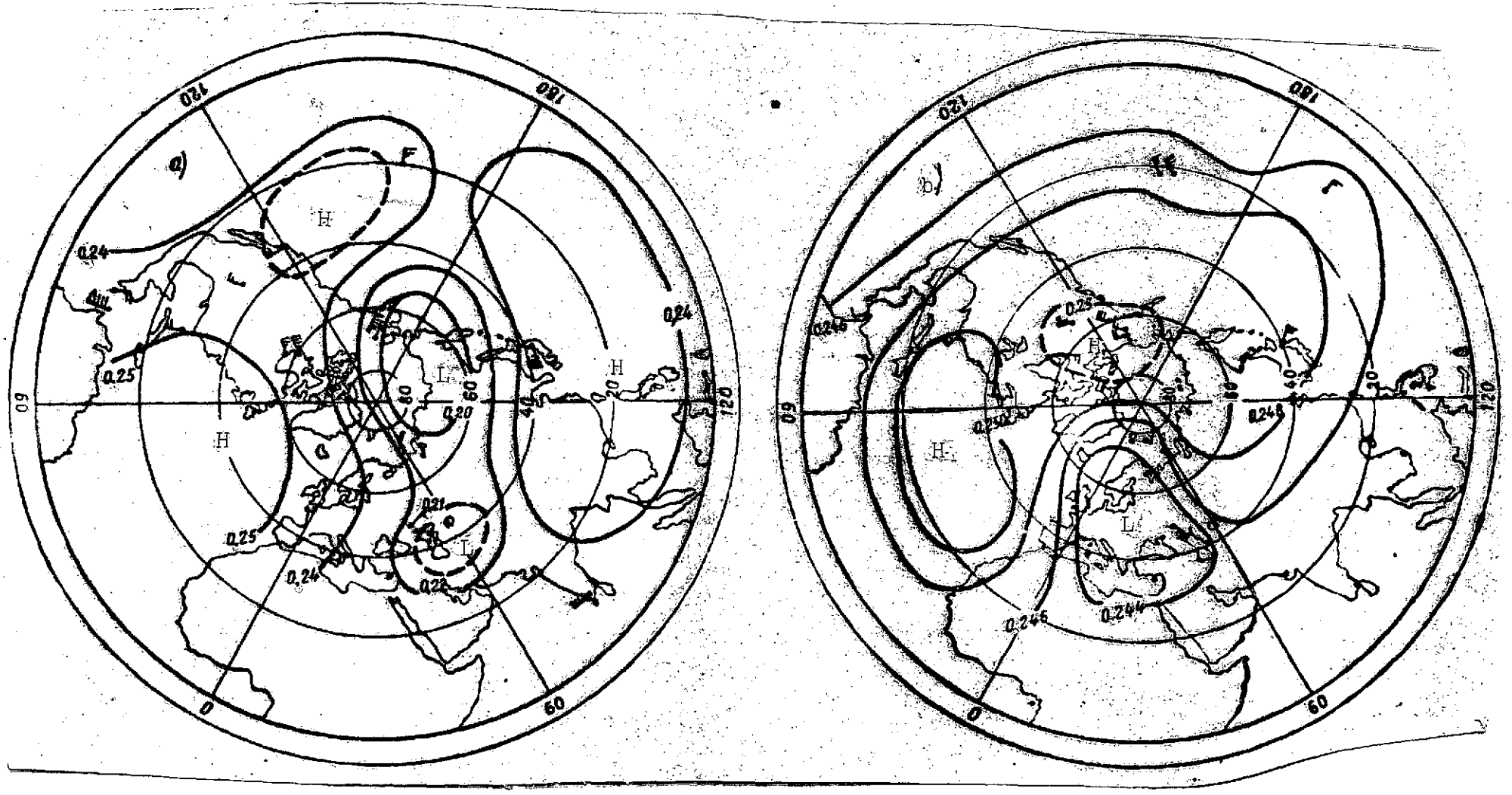

Fig. 2. The nature of the pressure field at 60 km altitude during spring reversal 14-20 April (a) and 28 April-1 May 1973 (b).

1. It follows from an analysis of the spring reversals of the preceding years (1958-1971) that later reversals take place after powerful strato-mesospheric warmings, with complete change of the circulation conditions in both the stratosphere and the mesosphere. In 1973, this process was observed in February. 1.5-2 months passed from this until reactivation of the high pressure areas. In this manner, following this indicator, the 1973 spring reversal should have occurred in the second half of April-first of May, which actually was observed.

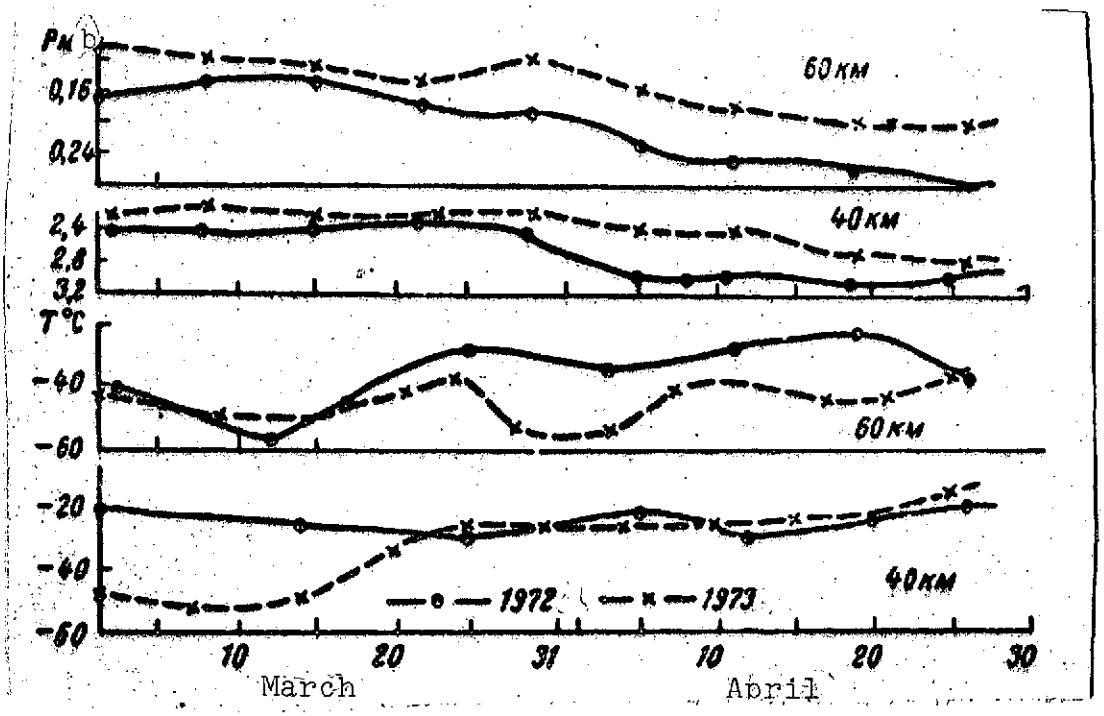

Fig. 3. Temperature and pressure changes in spring 1972 and 1973 (March-April) at altitudes of 40 and 60 km, from Hayes Island data.

2. A comparison of the temperatures, using Hayes Island data, in March-April 1972 and 1973, over the entire layer from 35 to 60 km, showed (Fig. 3) that the temperature was systematically 15-30°C lower in 1973, than in 1972. Such low temperatures should correspond to the stronger low pressure center in 1973. This was

observed, and it was disclosed, from an analysis of pressure changes in the center of the low (Fig. 3), which turned out to be considerably lower in 1973 than in 1972, also during March and April.

3. An analysis of the pressure regions in the 60°N latitude, 180° longitude and 60°N latitude, 30°W longitude zones (the zone of most frequent occurrence of stationary highs above the northern Pacific and Atlantic Oceans) in 1972 and 1973, demonstrated convincingly that the pressure in both zones in March and April 1973 was systematically lower than in the same zones in 1972, i.e., the /55 high pressure development was weaker. The weaker high pressure areas and stronger low pressure center of 1973 should have led to later field reversal, which turned out to be the case.

Conclusion

Systematic construction and analysis of contour charts, up to an altitude of 60 km, permits a considerably more complete study of the processes occurring in the stratosphere and mesosphere and determination of their times and directions.

Selected cases of the most interesting processes observed in the fall, winter and spring, during radical transformations of the pressure fields, are convincing, that the processes are of a more complicated nature than was thought up until this time, and that more detailed analysis of them provides the prerequisites for use of the patterns obtained in forecasting processes in the stratosphere and mesosphere.

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